

Yuanjun Liu^{1,2,5},
Caixia Wang²,
Yiping Ma²,
Yanyan Liu^{4,5},
Haiying Wu^{3,*},
Xiaoming Zhao^{2,*}

Study of the Dielectric Properties and Conductivity of Double Coated Glass Fibre Felt Composites

DOI: 10.5604/01.3001.0014.8233

¹ Donghua University,
Ministry of Education,
Key Laboratory of High Performance
Fibres & Products,
Shanghai 201620, China

² Tiangong University,
School of Textile Science and Engineering,
Tianjin 300387, China,
* e-mail: texzhao@163.com

³ Tiangong University,
School of Foreign Languages,
Tianjin 300387, China,
* e-mail: wuhaiyingheze1968@163.com

⁴ Qingdao University,
Institute of Functional Textiles
and Advanced Materials,
College of Textiles and Clothing,
Qingdao 266071, China

⁵ Lofftex industries Ltd.,
Binzhou 256622, China

Abstract

Graphite/talcum powder double-coated glass fibre felt composites were prepared using glass fibre felt as the base material, graphite as the surface absorbing agent, talcum powder as the underlying absorbing agent, epoxy resin E44 as the adhesive and low molecular 650 polyamide as the curing agent. The influences of the surface graphite content and underlying talcum powder content on the dielectric properties and conductivity of glass fibre felt composites were the main focus of the investigation. Results showed that when the frequency is less than 10^3 Hz, the values of the real and imaginary parts of the dielectric constant for double-coated glass fibre felt composites are largest when the surface graphite content is 50%. When the frequency is larger than 10^6 Hz, the value of the real part of the conductivity is largest when the graphite contents are 40% and 50%. When the frequency is less than 104Hz, the real part of the dielectric constant of the glass fiber mat composites is the largest when the talc content is 40%, and when talc content is 60%, the imaginary part of dielectric constant of glass fiber mat composites is the largest. The maximum loss tangent value for the composites occurs when the talcum powder content is 40%. When the frequency is larger, the value of the real part of the conductivity increases gradually.

Key words: graphite talcum powder, glass fibre felt, dielectric constant, coating.

Introduction

With the wide use of electromagnetic products, electromagnetic radiation and electromagnetic compatibility problems will pose more and more harm to the human body, which will attract more and more attention. Thus, exploring efficient electromagnetic shielding or absorbing materials will be the top priority for electromagnetic research [1-2]. In addition, the study of electromagnetic shielding or absorbing materials to improve the safety and reliability of electronic products, ammunition, fuses, precision electronic weapons and equipment, and so on, as well as to ensure personal safety and that communication and weapon systems remain open will assume great significance [3-7]. The dielectric properties and conductivity are the key indicators in determining the absorbing performance or shielding effectiveness, therefore they are important parameters in studying the

electromagnetic properties of materials [8-11]. The dielectric constant is one of the most important electromagnetic parameters of absorbing materials. It is the value of the ratio of the situation of a substance serving as a dielectric substance and the situation of the vacuum serving as a dielectric substance at the same capacitor, which is expressed with ϵ . The dielectric constant characterises the ability of accommodating induced polarisation charges for dielectric materials, and macroscopic quantities characterise the polarisation properties, whose value mainly depends on the complexity of the polarisation process in the electric field stimulation [12-13]. Conductivity is a measured value showing how strong or weak the ability of materials to transfer current is. When a voltage is added across both ends of a conductor, the charge carriers will cause the occurrence of flow in a certain direction, thus generating electric current.

Graphite is one of the allotropes for carbon as an element and belongs to the category of absorbing materials showing conduction loss. The absorbing mechanism works when the material is influenced by the interaction of the external magnetic field. The conductive absorbing material produced induces current in the conductor, which produces a magnetic field in contrast to the direction of the external magnetic field, which is offset by the external magnetic field [14-15].

Talcum powder has physical and chemical properties such as lubricity, sticky resistance, aiding flow, fire resistance, acid resistance, insulation, a high melting point, chemical inertness, good covering power, softness, good gloss and excellent adsorption forces, due to its crystallisation in a layered structure, and thus tends to easily split into flakes and provides special lubrication. Talcum powder shows inertness towards most chemical reagents, including not decomposing in contact with acids, is a poor conductor of electricity, and shows low thermal conductivity and high thermal resistance, for example, not breaking down when heated to as high a temperature as 900 °C. The main constituent of talcum powders is hydrated magnesium silicate. In the presence of an external electric field, magnesium ions and silicate ions will produce the polarisation phenomenon, giving rise to a level of shielding and absorbing performance.

In this investigation, graphite/talcum powder double-coated glass fibre felt composites were initially prepared using glass fibre felt as the base material, with its good thermal protection and mechanical properties, graphite as the surface absorbing agent, and talcum powder as the underlying absorbing agent. The influences of the surface graphite content and underlying talcum powder content on the real and imaginary parts of the dielectric constant,

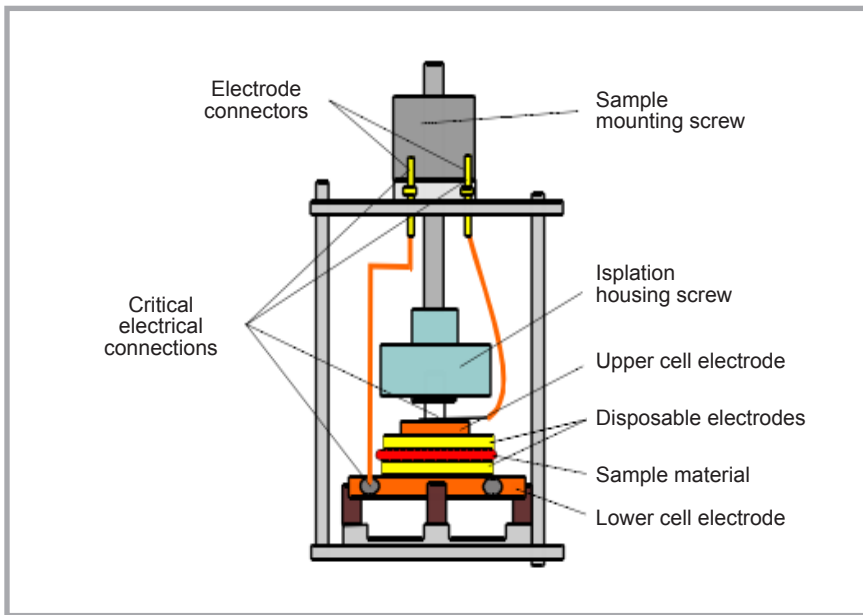


Figure 1. Test cell of dielectric spectrometer.

loss tangent value and real and imaginary parts of the conductivity of glass fibre felt composites were the main focus of the investigation.

Experimental

Main materials and reagents

Glass fibre felt (gram weight – 550 g/m², thickness – 6.15 mm), provided by Si-

chuang Glass Fibre Co., LTD in Zibo; graphite powder, provided by Dengke Chemical Reagent Co., LTD in Tianjin; talcum powder, provided by Dingsheng New Chemical Co., LTD In Tianjin; anhydrous ethanol, provided by Wind Ship Chemical Technology Co., LTD in Tianjin; E44 epoxy resin, provided by Assets Management Co., LTD of the China petrochemical group; 650 polyamide resin,

provided by Wuhui Harbor Adhesive Co., LTD in Hangzhou.

Test of dielectric properties and conductivity

Dielectric properties can indirectly reflect the absorbing properties of materials. In accordance with the test method of GB/T 5597-1999 microwave complex dielectric constant of a dielectric solid, the dielectric constant, loss tangent and conductivity of the graphite/talcum powder double-coated glass fibre felt composites were evaluated under conditions of constant temperature and humidity (20~22 °C and 64%~66% RH) using a BDS50 dielectric spectrometer (German Novocontorl GmbH Company) and No. 3 electrode (R = 30 mm in diameter). The test cell of the BDS50 dielectric spectrometer is shown in Figure 1 [16-19].

Preparation process for double-coated glass fibre felt composites

(1) A certain amount of adhesive (E44 epoxy resin) was poured into a beaker, a suitable amount of diluent (ethanol) added, and then stirring was undertaken until mixed evenly.

(2) An absorbing agent (talcum powder) was added to the above mixture, which was then stirred until mixed evenly.

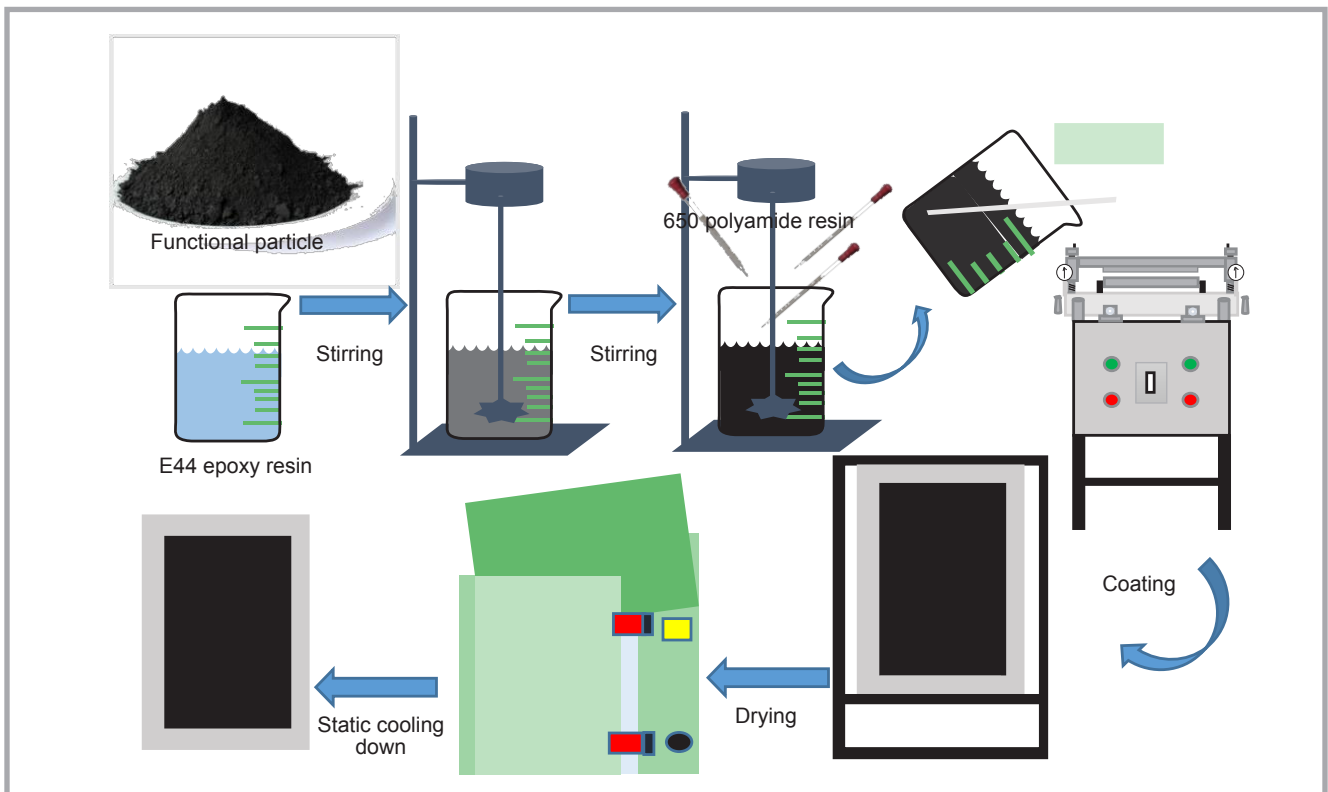


Figure 2. Preparation process of coating.

(3) A certain amount of a curing agent (650 polyamide resin) was added to the mixture in proportion, and then stirring was undertaken for 15 minutes until mixed evenly; at this point, the preparation of the underlying talcum powder coating agent was completed.

(4) Glass fibre felt was fixed on an LTE-S87609 coating machine (Swiss Werner Mathis Company), and the underlying talcum powder coating agent was coated on the glass fibre felt. The thickness of the underlying talcum powder coating was 0.5 mm.

(5) Stoving. The preparation process of the coating is shown in *Figure 2*.

(6) In the same way, the glass fibre felt coated by the talcum powder coating agent was fixed on the LTE-S87609 coating machine (Swiss Werner Mathis company) and coated with a graphite coating agent fibre. The thickness of the surface graphite coating was 0.5 mm.

(7) After storing, the preparation of the graphite/talcum powder double-coated glass fibre felt composites was completed. A structural model of the composites is shown in *Figure 3*.

Results and discussion

Influence of the surface graphite content on dielectric properties and conductivity

Six samples of the graphite/talcum powder double-coated glass fibre felt composites with different contents of graphite (surface coating) were prepared. The thickness of talcum powder was 0.5 mm and

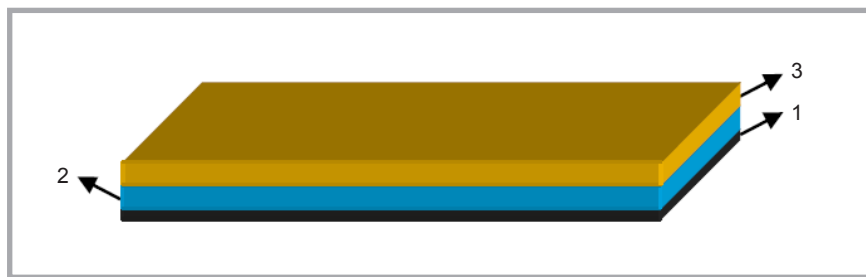


Figure 3. Structural model of composites: 1 – Base cloth, 2 – Talcum powder (underlying coating) & 3 – Graphite (surface coating).

its content 30%. The thickness of graphite was 0.5mm and its content was 0%, 10%, 20%, 30%, 40% & 50%, respectively.

The dielectric constant is one of the most important electromagnetic parameters of absorbing materials, and it is the value of the ratio of the situation of a substance serving as the dielectric substance and the situation of a vacuum serving as the dielectric substance at the same capacitor, which is expressed by ϵ . The dielectric constant characterises the ability of accommodating induced polarisation charges for dielectric materials, and the macroscopic quantities characterise the polarisation properties. Its value mainly depends on the complexity of the polarisation process in electric field stimulation, where the more material, and more polarised and induced charges in the external electric field, the larger the value of the dielectric constant and the smaller the vice. The dielectric constant is usually expressed as $\epsilon = \epsilon' - j\epsilon''$, where ϵ' is the real part of the dielectric constant and ϵ'' the imaginary part, which are the macro parameters of the polarisation charges and dielectric loss. The real part of the dielectric constant represents the ener-

gy storage of materials in the exchange of the dielectric substance, while the imaginary part shows the energy loss in the electric field. The energy loss can be understood as being caused by the induction electric dipole moment, producing a relative displacement in the interior of the material.

The loss tangent of materials, $\tan\delta$, characterises the capability of absorbing waves and attenuation, where the larger the value of the electromagnetic loss tangent, the better the absorbing performance of the material. In $\tan\delta = \tan\delta\epsilon + \tan\delta\mu$ $\epsilon''/\epsilon' + \mu''/\mu'$, $\tan\delta\epsilon$ is the electric loss tangent and $\tan\delta\mu$ the magnetic loss tangent.

As can be seen from *Figure 4*, when the frequency is less than 10^3 Hz, the value of the real part of the dielectric constant for graphite/talcum powder double-coated glass fibre felt composites decreases with increasing frequency. The value of this constant is largest when the surface graphite content is 50%, and the next highest values are when the surface graphite content is 30% and 40%, respectively. When the frequency is between

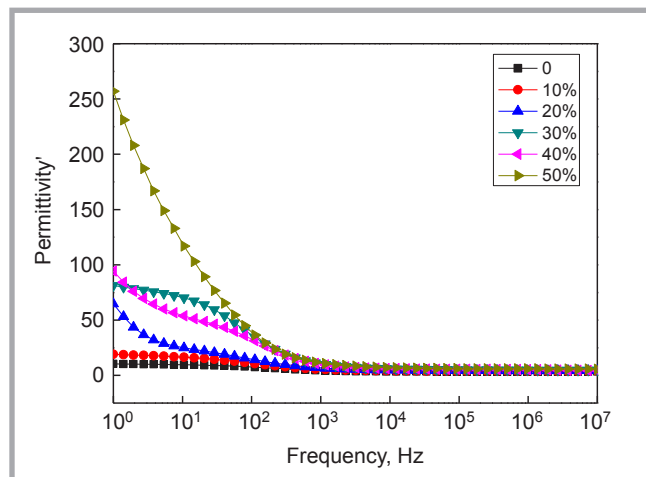


Figure 4. Influence of surface graphite content on the real part of the dielectric constant.

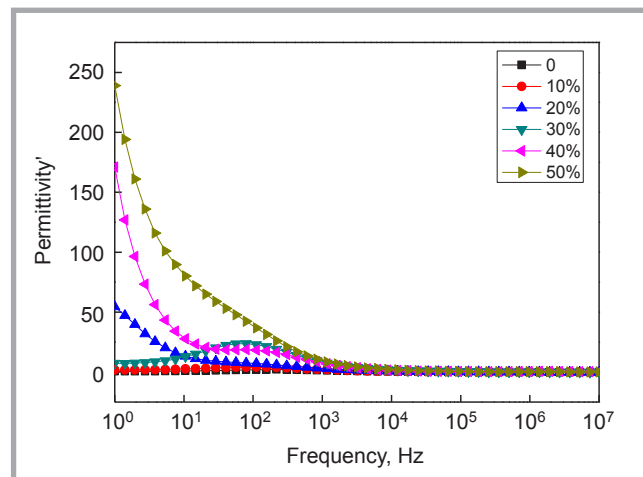


Figure 5. Influence of the surface graphite content on the imaginary part of the dielectric constant.

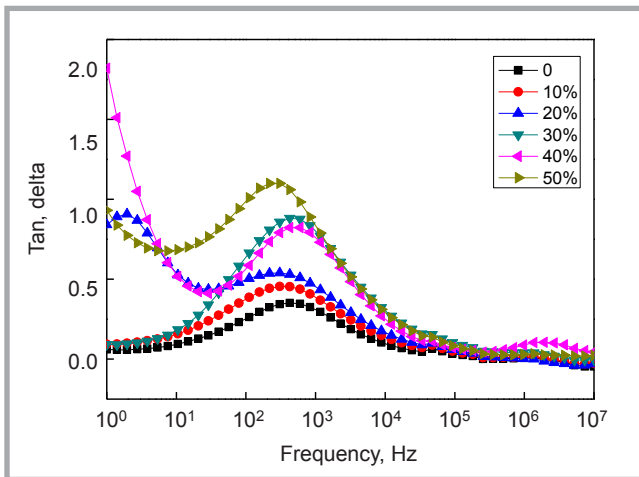


Figure 6. Influence of the surface graphite content on the loss tangent value.

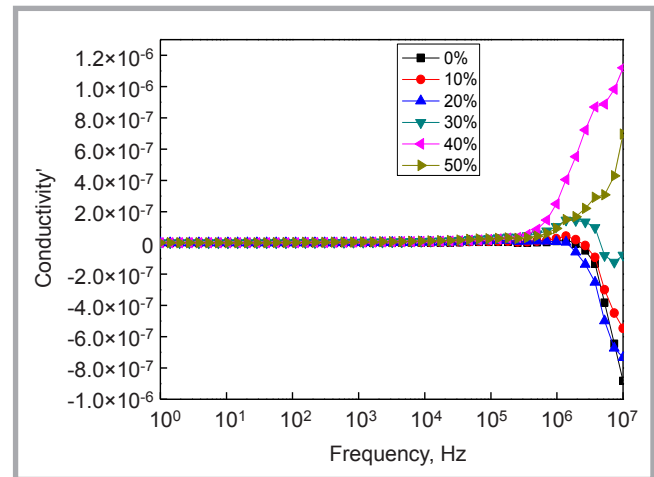


Figure 7. Influence of surface graphite content on the real part of the conductivity.

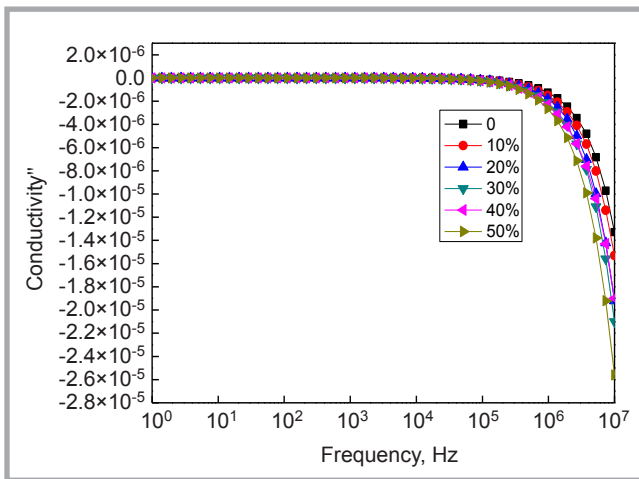


Figure 8. Influence of the surface graphite content on the imaginary part of the conductivity.

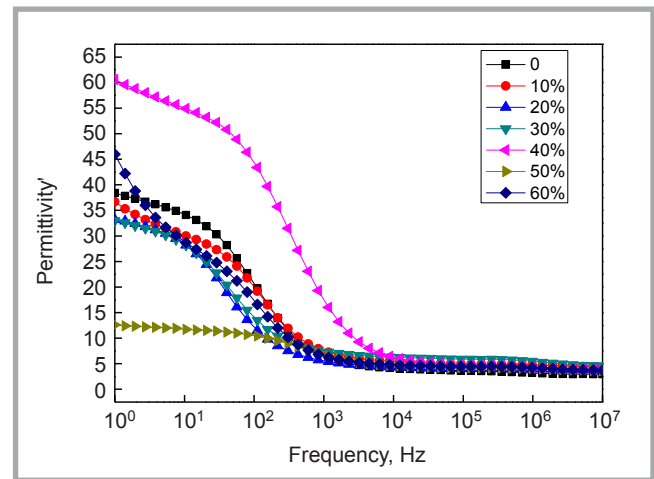


Figure 9. Influence the talcum powder content on the real part of the dielectric constant.

10^3 Hz and 10^7 Hz, the values of the real part of the dielectric constant are almost the same, which means that the graphite content has little influence on this constant. As can be seen from **Figure 5**, when the frequency is less than 10^3 Hz, the value of the imaginary part of the dielectric constant for graphite/talcum powder double-coated glass fibre felt composites decreases with increasing frequency; the value this constant is largest when the surface graphite content is 50%, and the next highest values are when the surface graphite content is 40% and 20%, respectively. When the frequency is between 10^3 Hz and 10^7 Hz, the values of the imaginary part of the dielectric constant are almost the same, which means that the graphite content has little influence on this constant. As can be seen from **Figure 6**, with increasing frequency, the loss tangent value for graphite/talcum powder double-coated glass fibre felt composites

increases first and then decreases; when the graphite content is 40% and 50%, the loss tangent value is the maximum.

Graphite is one of the allotropes of carbon as an element, whose arrangement comprises multiple hexagons in a honeycomb pattern, combining covalent bond and forming covalent molecules. Because each carbon atom will emit an electron, electrons can move freely, thus graphite belongs to the conductive bodies. The distance between the layer and that of graphite crystal was about 340 PM, which was bigger, relying on the van der Waals force; namely, the substance belonged to molecular crystals between the layers. However, due to the combination between carbon atoms on the same surface layer being very strong, which was very difficult to break, the melting point of the graphite was high and the chemical property stable. The graphite belonged to

the absorbing materials of conduction loss, whose mechanism was that when the material was influenced by the interaction of the external magnetic field, the conductive absorbing material produced induced current in the conductor, which produced an magnetic field in the opposite direction of the external magnetic field, which was offset by the external magnetic field.

As can be seen from **Figure 7**, when the frequency is less than 10^6 Hz, the surface graphite content has little influence on the real part of the conductivity for graphite/talcum powder double-coated glass fibre felt composites, and the value of the real part of the conductivity was almost zero. When the frequency is larger than 10^6 Hz, and when the graphite content is 40% and 50%, the value of the real part of the conductivity is largest, which suggests that the energy dissipa-

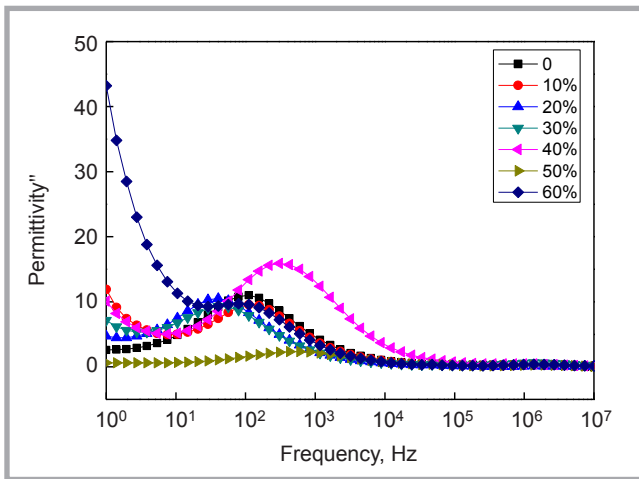


Figure 10. Influence of talcum powder content on the imaginary part of the dielectric constant.

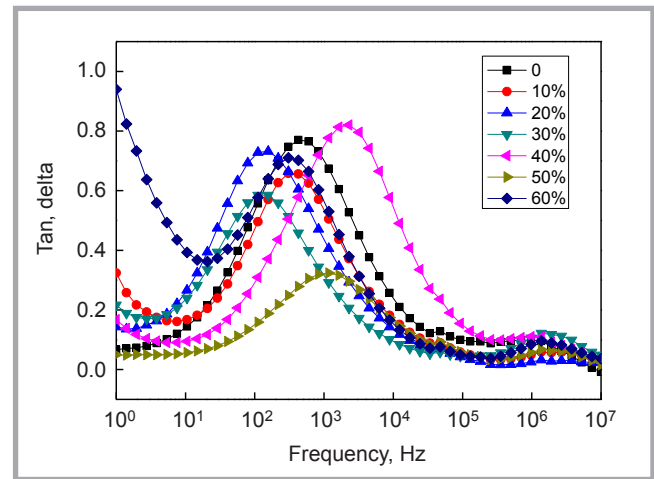


Figure 11. Influence of talcum powder content on the loss tangent value.

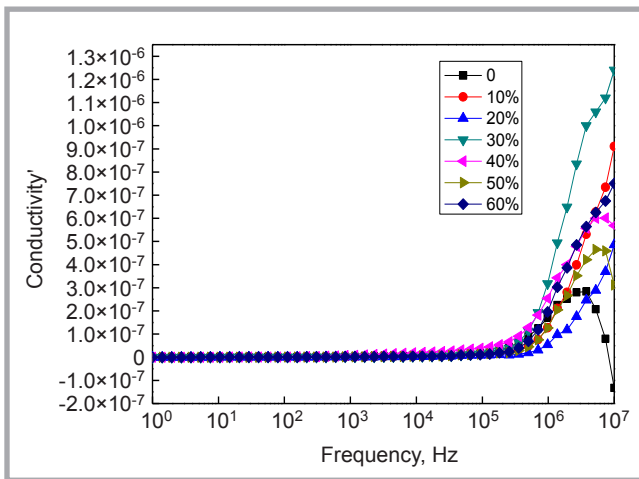


Figure 12. The influence of the talcum powder content on the real part of the conductivity.

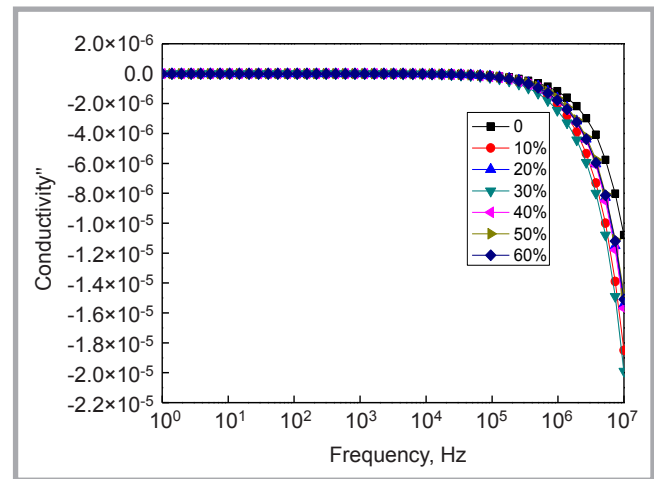


Figure 13. Influence of talcum powder content on the imaginary part of the conductivity.

tion is larger. As can be seen from **Figure 8**, when the frequency is less than 10^5 Hz, the value of the imaginary part of the conductivity remains virtually unchanged, and that of the conductivity is almost zero. The surface graphite content has little influence on the imaginary part of the conductivity for graphite/talcum powder double-coated glass fibre felt composites. When the frequency is larger than 10^5 Hz, the decrease in the value of the imaginary part of the conductivity of graphite/talcum powder double-coated glass fibre felt composites is most pronounced when the graphite content is 50%, which means that the energy conversion is highest.

Influence of the underlying talcum powder content on the dielectric properties and conductivity

Seven samples of graphite/talcum powder double-coated glass fibre felt com-

posites with different contents of talcum powder (underlying coating) were prepared. The thickness of graphite was 0.5 mm and the content 40%. The thickness of talcum powder was 0.5 mm and the content 0%, 10%, 20%, 30%, 40% & 50%, respectively.

As can be seen from **Figure 9**, when the frequency is less than 10^4 Hz, the value of the real part of the dielectric constant for graphite/talcum powder double-coated glass fibre felt composites shows a gradually decreasing trend with increasing frequency, which is largest when the talcum powder content is 40%. When the frequency is between 10^4 Hz and 10^7 Hz, the values of the real part of the dielectric constant are almost the same. As can be seen from **Figure 10**, when the frequency is less than 10^4 Hz, the value of the imaginary part of the dielectric constant is largest when

the talcum powder content is 60%, and thus the loss of electromagnetic waves is largest. When the frequency is 100 Hz, the value of the imaginary part of the dielectric constant of graphite/talcum powder double-coated glass fibre felt composites reaches the maximum value. As can be seen from **Figure 11**, the loss tangent value of graphite/talcum powder double-coated glass fibre felt composites shows an overall trend of first increasing and then decreasing. When the talcum powder content is 40%, the maximum value of the loss tangent value for the composites is achieved, and when the frequency is larger than 10^5 Hz, the loss tangent values are nearly the same.

As can be seen from **Figure 12**, when the frequency is smaller, the values of the real part of the conductivity of graphite/talcum powder double-coated glass fibre felt composites are the same. Thus, the

talcum powder content has little influence on the real part of the conductivity for fibre these composites, and the value is almost zero. When the frequency is larger, this value gradually increases. Among the samples, the increase was most pronounced when the talcum powder content was 40%, which means that the energy conversion is the largest. As can be seen from **Figure 13**, when the frequency is smaller, the talcum powder content has little influence on the imaginary part of the conductivity. When the frequency is larger, the value of the imaginary part of the conductivity rapidly decreases. Among the samples, the decrease in the value of the imaginary part of the conductivity of graphite/talcum powder double-coated glass fibre felt composites is most pronounced when the talcum powder content is 30%, which means that the energy conversion is the smallest.

Conclusions

(1) When the frequency is less than 10^3 Hz, the values of the real and imaginary parts of the dielectric constant for graphite/talcum powder double-coated glass fibre felt composites are both largest when the surface graphite content is 50%. The next largest values are when the surface graphite content is 30% and 40%, respectively. With increasing frequency, the loss tangent value of glass fibre felt composites increases first and then decreases, with the largest loss tangent value occurring when the graphite content is 40% and 50%, respectively.

(2) When the frequency is less than 10^4 Hz, the value of the real part of the dielectric constant of glass fibre felt composites is largest when the talcum powder content is 40%. The value of the imaginary part of the dielectric constant of glass fibre felt composites is largest when the talcum powder content is 60%. When it is 40%, the maximum loss tangent value for the composites is achieved.

Acknowledgements

This work was supported by Key Laboratory of High Performance Fibers & Products, Ministry of Education, Donghua University, Shanghai. This work was supported by Undergraduate Innovation and Entrepreneurship Training Program, and the project number is 201910058004.

References

1. Liu YJ, Liu BC, Zhao XM. The Influence of the Type and Concentration of Oxidants on the Dielectric Constant of the Polypyrrole-Coated Plain Woven Cotton Fabric. *The Journal of The Textile Institute* 2018; 109: 1127-1132.
2. Liu YJ, Liu YC, Zhao XM. The Influence of Dopant on the Dielectric Properties of Flexible Polypyrrole Composites. *The Journal of The Textile Institute* 2017; 108: 1280-1284.
3. Liu YJ, Liu YC, Zhao XM. The Influence of Pyrrole Concentration on the Dielectric Properties of Polypyrrole Composite Material. *The Journal of The Textile Institute* 2017; 108: 1246-1249.
4. Liu YJ, Liu YC, Zhao XM. The Research of EM Wave Absorbing Properties of Ferrite/Silicon Carbide Double Coated Polyester Woven Fabric. *The Journal of The Textile Institute* 2017; 109: 106-112.
5. Liu Y, Zhao X. Experimental Studies on the Dielectric Behaviour of Polyester Woven Fabrics. *FIBRES & TEXTILES in Eastern Europe* 2016; 24, 3(117): 67-71. DOI: 10.5604/12303666.1196614.
6. Ahmad S, Sultan A, Raza W, Muneer M, Mohammad E. Boron Nitride Based Polyaniline Nanocomposite: Preparation, Property, and Application. *Journal of Applied Polymer Science* 2016; 133: 1-9.
7. Balint R, Cassidy NJ, Nate, Cartmell S H. Conductive Polymers: Towards a Smart Biomaterial for Tissue Engineering. *Acta Biomaterialia* 2014; 10: 2341-2353.
8. Liu YJ, Zhao XM. The Influence of Dopant Type and Dosage on the Dielectric Properties of Polyaniline/Nylon Composites. *The Journal of The Textile Institute* 2017; 108: 1628-1633.
9. Liu YJ, Zhao XM, Tuo X. Preparation of Polypyrrole Coated Cotton Conductive Fabrics. *The Journal of The Textile Institute* 2017; 108: 829-834.
10. Kumar A, Jangir LK, Kumar M, Kumar V, Awasthi K. Electrical Behavior of Dual-Morphology Polyaniline. *Journal of Applied Polymer Science* 2016; 133: 1-9.

11. Liu YJ, Zhao XM, Tuo X. The Research of EM Wave Absorbing Properties of Ferrite/Silicon Carbide/Graphite Three-Layer Composite Coating Knitted Fabrics. *The Journal of The Textile Institute* 2016; 107: 483-492.
12. Maity S, Chatterjee A, Singh B, Singh A P. Polypyrrole Based Electro-Conductive Textiles for Heat Generation. *The Journal of The Textile Institute* 2014; 105: 887-893.
13. Yu H, Nonn A, Heider D, Advani S. Model-Based Characterization and Enhancement of the Through-Thickness Thermal Conductivity of Polymer Composites Using Infrared Camera. *International Journal of Thermal Sciences* 2014; 80: 118-125.
14. Yu MM, Chen SH, Zhou Z, Zhu MF. Novel Flexible Broadband Microwave Absorptive Absorptive Fabrics Coated with Graphite Nanosheets/Polyurethane Nanocomposites. *Progress in Natural Science Materials International* 2012; 22: 288-294.
15. Zhang XZ, Sun W. Microwave Absorbing Properties of Double Layer Cementitious Composites Containing Mn-Zn Ferrite. *Cement and Concrete Composites* 2010; 32: 726-730.
16. Liu Y, Wang H, Zhang Y, Wang X, Yin G, Han X, Niu J. Study on the Electromagnetic and Mechanical Properties of Coated Composites. *FIBRES & TEXTILES in Eastern Europe* 2020; 28, 6(144): 89-97. DOI: 10.5604/01.3001.0014.3803.
17. Liu Y, Wang Y, Wu X, Zhang L, Niu J. Influence of Wave-Absorbing Functional Particles on the Electromagnetic Properties and Mechanical Properties of Coated Composites for Nickel Powders. *FIBRES & TEXTILES in Eastern Europe* 2020; 28, 5(143): 75-81. DOI: 10.5604/01.3001.0014.2389.
18. Liu Y, Yang Y, Yang Z, Liu Y, Su Y, Niu J. Influence of the Thickness of Graphene Coating on the Electromagnetic and Mechanical Properties of Double-Layer Coated Basalt Fibre Fabrics. *FIBRES & TEXTILES in Eastern Europe* 2020; 28, 5(143): 69-74. DOI: 10.5604/01.3001.0014.2388.
19. Liu Y, Zhao X. Influence of the Yarn Fineness and Stitch Length of Polyester Knitted Fabric on the Dielectric Constant. *FIBRES & TEXTILES in Eastern Europe* 2019; 27, 6(138): 63-66. DOI: 10.5604/01.3001.0013.4469.

Received 02.03.2020

Reviewed 11.01.2021